

SUBJECT: Post Apollo Lunar Exploration  
Case 105-1

DATE: June 17, 1970

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ABSTRACT

A range of possible lunar exploration activities is described for the decade after Apollo. At present, there are no firm NASA plans for this time. Assumed priorities are, to complete the descriptive characterization of the Moon, to pursue particular scientific problems, and lastly, to study the Moon broadly and in considerable depth. It is believed that such priorities are valid whether the continued lunar activity is motivated, for instance, by pure science, exploration, growth of man's ability to work in space, or terrestrial applications. In order of increasing ambition, the potential activities are:

(1) Ground based analysis of existing data, including the preparation of geological charts of the lunar far-side.

(2) Orbital survey missions to complete global photographic coverage at intermediate resolution (30-90m) and at low and high sun angles. The Apollo J missions may identify survey instruments of particular usefulness in characterizing the Moon.

(3) If surface missions are planned, high resolution orbital survey to select sites for scientific interest and landing safety.

(4) A limited number of surface missions consistent with unmanned point landers (Surveyor-Viking) or with Apollo J missions, to complete the sampling of major near-side terrain types. Some additional sites on the far-side, limbs and poles will be desirable.

(5) Surface missions to attack particular problems in the light of partial understanding. These involve extended capability: in manned missions, stay-times of a lunar day, and in unmanned missions, remote-controlled vehicles or a substantial (many flight) program. For both manned and automated systems, this level is the most similar to intensive exploration of Mars.

It is believed that the rationale for a surface or an orbital base will arise from operations, logistics, or safety rather than from scientific requirements.

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MEMORANDUM FOR FILE

1.0 Introduction

The Apollo program will end, depending on the use of Apollo 18 and 19, in two to four years after four to six more landings. According to the current baseline plan, Space Task Group Option Two, (1) lunar flight would resume in 1981; present budget pressures are tending to widen this gap to ten years or more. It is debatable whether such a gap is acceptable. The purpose of this paper is to clarify discussion of this issue by describing a range of objectives and systems which could fill the gap. Combinations of automated and manned activities are considered.

The possible reasons for continued Lunar Exploration are diverse. They include: pure science, maintaining the effort to understand the Moon's origin and evolution; exploration; growth in man's ability to work in space; applications to understanding of the Earth; search for potential resources; gaining operational experience for planetary missions; and so forth.

To simplify this paper, it is assumed that in this period the work to be done at the Moon is scientific, regardless of motivation. It is then useful to distinguish three levels of ambition. These are summarized in Table 1.1.

The first level is the Characterization of the Moon as a planet. The activity is primarily descriptive and involves planet-wide observation, analysis to identify distinctive terrain types (maria, terrae, etc.), and then performing exploratory measurements at typical sites within these terrains.

The second level includes Particular Studies of specific features and processes. It is more classically "scientific", e.g., guided by hypotheses, and is pursued to increase our understanding of the Moon and of the planets, particularly Earth. This level can also be described as Comparative Planetology, and clearly overlaps the other two.

The third level corresponds to a very detailed Encyclopedic Study of the Moon, including both typical and atypical areas. These very intensive studies are readily conceived as part of the exploitation or use of the Moon; it is doubtful that they are pertinent to a "gap-filling" program in the decade 1975-1985.

These levels are used to guide the discussions of objectives, missions, and systems, in sections 2, 3, and 4 below. Specific examples are used, but the intent is to describe classes of objectives, missions, and system capabilities. The precise options which are available are sensitive to national and space program considerations outside the scope of the paper. These sensitivities are discussed briefly in section 5. Section 6 contains a summary and conclusions.

TABLE 1.1

## THREE LEVELS OF STUDY OF THE MOON (OR ANY PLANET)

LEVEL	ACTIVITY, DESCRIPTORS	DATA BASE, UNDERSTANDING	TYPICAL SYSTEMS	SYSTEM MEASURES*		
				MEN	LIFE	P/L
I	CHARACTERIZATION DESCRIPTIVE SCIENCE EXPLORATION GLOBAL PLANETOLOGY	EARTH BASED DATA-- WHOLE PLANET GEOLOGY (USGS MAPS)  PLUS  EARLY FEEDBACK	EARTH-BASED TELESCOPES AND RADAR	---	---	---
			RANGER, MARINER FLYBY LUNAR ORBITER, MARINER ORBITER, SURVEYOR	---	MINUTE	10 <sup>2</sup>
			ALSEP, VIKING, "HEAVY"	---	MONTH	10 <sup>2</sup>
			SURVEYORS? & ORBITERS	---	YEAR	10 <sup>2</sup>
			APOLLO H	2	DAYS	10 <sup>3</sup>
II	PARTICULAR STUDIES  SCIENCE (GUIDED BY HYPOTHESIS)  COMPARATIVE PLANETOLOGY  APPLIED SCIENCE (GOAL-DIRECTED)	ABOVE, PLUS: APOLLO AND U/M PROGRAM RESULTS.  ANALYSIS BY "LUNAR SCIENCE COMMUNITY"	APOLLO J	2	DAYS	10 <sup>3</sup>
			(VOYAGER) (PROSPECTOR) REMOTE CONTROL ROVERS	---	YEAR	10 <sup>2-3</sup>
			APOLLO DUAL MISSIONS, CSM/LM-B	T <sup>†</sup>	YEAR	10 <sup>2</sup>
				2	WEEKS	10 <sup>3-4</sup>
				3	MONTH	10 <sup>4</sup>
III	ENCYCLOPEDIA STUDIES INTENSIVE STUDY OF A BROAD RANGE OF PROBLEMS.  LUNAR SCIENCE IN DEPTH  RESOURCES UTILIZA- TION, EXPLOITATION	ABOVE, PLUS GROWTH, SCIENCE ACTIVITY DISTINCTION IS ONE OF SCALE ONLY.	LUNAR ORBITING BASE/ LM-B	3	YEARS (REUSED)	10 <sup>4</sup>
			"FREQUENT, LOW-COST" LM-B TYPE MISSIONS		"	
			"PERMANENT BASES", ORBITAL OR SURFACE.	?	PERMANENT	10 <sup>4-5</sup> ?

\*THE NUMBER OF MEN ON A GIVEN SURFACE MISSION AND THE ORDER OF MAGNITUDES OF SYSTEM ACTIVE LIFE AND DISPOSABLE PAYLOAD IN POUNDS ARE GIVEN.

†T SYMBOLIZES "TELEFACTOR" FOR THE AUTOMATED ROVER.

## 2.0 Scientific Objectives

### 2.1 Introduction:

The National Academy of Sciences<sup>(2)</sup> has formulated long-range goals for the NASA Lunar Program. The major activities to be undertaken in order to meet these goals are summarized in Appendix A. In this section, using the three activity levels of Table 1.1, we separate scientific objectives into a completable set and two open sets. Thus, a range of objectives is defined, corresponding to a range of possible lunar missions and systems described below. The completable set, Level I, corresponds to acquiring well-defined data, much of which the unmanned programs and Apollo will get, and analysing those data.

#### 2.2.1 Level I - Exploration and Characterization

Here we are interested in studies of global scope with the aim of characterizing the Moon as one of the planets. There should be emphasis on getting representative data from each of the major classes of features and processes. The activity has proceeded from Earth-based observations (visual, radio, IR), through the investigations of the unmanned reconnaissance programs (Ranger, Surveyor, Orbiter), to the selection of a small number of characteristic sites for more detailed surface exploration in the Apollo Program.

The base of understanding for this level is the body of lunar science developed since Galileo. The critical set of analyses is descriptive, in particular, the United States Geological Survey geological maps,<sup>(3)</sup> prepared on the 1:10<sup>6</sup> base maps of the Air Force Chart and Information Center.<sup>(4)</sup> These maps were prepared from Earth-based data at a resolution of about one kilometer.

For the purposes of this paper, Level I "Characterization" will be considered complete when (a) this descriptive analysis at one kilometer is complete for the entire Moon; (b) the distinctive terrain types have been "sampled" (local high resolution topography measurements, some chemical and petrographical evaluation); and (c) some number of "whole Moon" geophysical measurements are made. Additional measurements performed to verify hypotheses about the origin and evolution of the Moon are assigned to Level II.

Most of the objectives at this level can be met by analysis of existing data, unmanned orbital programs and a mix of manned and unmanned surface explorations at selected landing sites. Accordingly, for the manned systems, there is no great need for mobility or stay-time beyond that of the Apollo J missions.

### 2.2.2 Achievements by the End of Apollo

Lunar Orbiters photographed practically all the near-side at a resolution of 60-90m and the far-side at about 1 km. They also provided one-meter resolution photography of selected near-side sites comprising about 1% of the lunar surface. Apollo CSM photography will extend the high resolution coverage to about 5% of the lunar surface (Appendix B).

The geological exploration and sample return from Apollo should allow the characterization of the major types of geological features and terrain; i.e., maria, highlands, major crater types, ejecta blankets, "volcanic" areas and some rille types. This is treated further in section 3.

The ALSEP geophysical experiments will measure particles, fields, heat flow and seismic activity at the lunar surface, and several experiments (magnetometer, seismometer, heat flow) will permit some inferences about the lunar interior.

The CSM orbital experiments will provide an opportunity to evaluate remote sensing by comparison with ground truth from the landing sites. The results should indicate which measurements (Appendix B) have the greatest potential for later orbital studies of the whole Moon.

### 2.2.3 Post-Apollo Data Deficiencies

In description and in data, there are obvious deficiencies with respect to the lunar far-side. Negligible geological analysis is being currently performed using the existing, 1 km photography. Additional far-side photography at moderate (30-90m) resolution and low sun angle is needed to complete a uniform documentation of lunar topography.\* The same capability could fruitfully acquire moderate resolution (30-90m) coverage of the whole Moon at a variety of sun angles, which would further assist in compiling regional geological maps.

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\* A rationale for this "uniform documentation" is the following. A useful photographic Atlas of a whole planet might have  $10^2$  pages, each a photograph of good quality, perhaps  $10^4$  picture elements on a side or  $10^8$  elements per picture. The Atlas then contains  $10^2 \times 10^8 = 10^{10}$  picture elements. The area of the Moon is approximately  $36 \times 10^{12} \text{m}^2$ . Then each picture element represents an area of  $3600 \text{m}^2$  and the equivalent resolution is 60m.

Insofar as additional manned or automated landings are planned, a high resolution capability (1-10m) is highly desirable for the examination of candidate sites, for both scientific and operational reasons.

Section 3 (Missions) suggests on the basis of current understanding that a modest number of sites beyond Apollo are valuable for Level I characterizations. As noted, we have, at present, little indication of the ways in which the far side differs from the near. Reasonably complete characterization will probably require additional landings.

## 2.3 Level II - Particular Studies

### 2.3.1 Introduction

Level II corresponds to pure science in the sense of experiment guided by hypothesis, and to applied science in the sense of goal-directed investigations. Examples of the latter are site surveys for lunar observatories or bases, and searches for potential resources.

Scientific interest is directed to those things crucial to our understanding of the origin, evolution, and processes of the Moon vis á vis the other planets, especially the Earth. This study of the Moon may have some useful Earth applications. For example, the study of lunar volcanic or seismic activity may provide new information about how these processes operate on the Earth.

The base of understanding for Level II activity includes the descriptive analyses resulting from Level I, and hypotheses as to lunar processes and origin. The current lunar program has considerable Level II content; the geologic maps are annotated with interpretive hypotheses, e.g., "volcanic", "impact crater". This is in part because, in contrast with Mars, Venus, or the other planets, we have had good "characterization" data about the Moon for many years. There have been many theories about the origin of the Moon (fission, capture, twin planet) and its surface features (impact, volcanism). However, there has been until recently insufficient experimental data to permit detailed tests of the theories.

### 2.3.2 Achievements by the End of Apollo

The Apollo results will raise specific questions subject to verification and will lead to the framing of hypotheses subject to quantitative test. Already, the anomalous seismic results and the unexpectedly large remanent magnetic fields have raised some interesting questions.

### 2.3.3 Deficiencies

Owing to the nature of Level II, most specific data deficiencies cannot be identified except -- as in section 3 -- insofar as sites which test our current understanding will not be visited. As noted, Level II is open-ended and thus not "completable". Nevertheless, following Apollo, provided that funds for analysis are available, we will have a deeper understanding and extended experimental requirements.

The scope of these tests may be both local and regional. A regional study might include the characterization and explanation of a major feature -- a mare, "volcanic" area, or larger crater. A more local study might include the investigation of the boundaries between terrain elements.

In general, the experiments and investigations at this level are more sophisticated, possibly including active seismic and EM sounding, deep drilling, deployment of advanced geophysical packages, heat flow, and detailed, extensive surface exploration. However, less sophisticated but extensive operations may also appear. For instance, spot checks on the homogeneity of regions might be made with simple, hard-landed instrument packages.

Certainly there is a need for increasing surface mobility, including perhaps a flying capability for investigating ridge tops, crater walls, and rilles. Regional studies would require a range of the order 100-1,000 km, achieved by multiple landing or general mobility. More local studies would require a range of the order 10-100 km.

For a manned exploration program at this level, the stay-time requirement probably falls in the category of days to weeks. This requires a considerable upgrading of the Apollo capability and, in general, increased accessibility. A supplemental automated capability (at least of ALSEP class) is surely necessary.

Within this level, one might also include the use of the Moon as a platform for nonlunar studies, i.e., observatories for optical and radio telescopes. Such observatories might well be automated and require man only for establishment, checkout and maintenance.

The objectives, stay-times, surface mobility and operations for the manned activity at this level might be closest to those needed in the first stages of a manned planetary program. Perhaps at this level the lunar program comes closest to being a test bed for the manned planetary program (see Section 5).

A purely unmanned program at this level would be very ambitious. Large automated observatories, orbiters and/or rover-telefactories with material-properties experiments would be typical. Tradeoff studies would consider the automated return of samples versus in-situ analysis. In either case, systems permitting communications to the poles, limbs and far-side will be desirable.

#### 2.4 Level III - Encyclopedic studies

Level III corresponds to a decision to investigate the Moon with considerable intensity, as part of a program best described as exploitation, colonization, or utilization. It is not properly an option for the late '70's and is included only as a qualitative bound to the Level II activities. The scientific activities are modelled as a broad range of in-depth studies of lunar problems, both typical and atypical. The search for lunar resources and initial use thereof would run in parallel with this activity.

With respect to surface operations this level most likely would require, over the years, planet-wide mobility and long life surface and/or orbital bases. Such bases might ultimately lead to permanent bases, self-sufficient in areas where utilizable resources can be found.

### 3.0 Missions

#### 3.1 Introduction

In this section scientific objectives and spacecraft systems are discussed in terms of missions to specific sites. Most sites, even among those designated for Apollo, are suitable for Level II study. Level III, involving long-term habitation on the Moon and planet-wide mobility, is not discussed here.

Constraints and accessibility are also considered.

#### 3.2 Sites

Levels I and II as described in Section 1, involve characterization of distinct types of terrain and particular studies of specific features, processes, and problems.

Table 3.1 (A) lists major terrain types, which require Level I characterization, and representative sites which have been discussed for Apollo.<sup>(5)</sup> Sites which have been visited by Apollo and Surveyor are noted, and also a recent set of tentative sites for Apollo 14-19. Two or three major terrain types will probably not have been visited, for a number of Apollo missions are planned for Level II sites (e.g. hypothesized volcanic and impact craters) within known terrains, and some missions might not be successful. In particular, no site has been proposed for the "Old Pitted Plains" of the southern highlands or for the north polar region.

As indicated in Section 2, the far-side of the Moon has not been mapped geologically, and there are neither moderate resolution pictures for site selection nor high resolution pictures for mission planning. Hence neither the terrain classification nor the list of sites is complete, and Table 3.1 (A) can be expected to extend as more photographic data become available.

Table 3.1 (B) lists local structures, generally Level II sites representative of hypothesized impact or vulcanism, or distinguishable features of doubtful origin<sup>(5)</sup>. To these can be added the polar regions, where permanently shaded areas may contain volatiles, and two suggested far-side sites. These are Tsiolkovsky, a rare occurrence of dark mare fill material on the far-side, and Crater 211, photographed by Apollo, which El-Baz<sup>(6)</sup> has interpreted as the site of volcanic dikes. Again, additional data will extend our lists both of sites and of problems.

Table 3.2<sup>(7)</sup> shows a hypothesized relationship between Level II sites, as presently understood, and lunar history, composition and processes. The two far-side sites have been added. The geographical coverage of these sites is broad; relatively few will be visited by Apollo.

The description of a site as Level I or Level II depends partly on its terrain, partly on the level of scientific sophistication involved in the mission, and partly on the current operational capability. This is demonstrated for Apollo systems by Figs. 3.1 and 3.2.<sup>(7)</sup> Fig. 3.1 is typical of Apollo H missions and Level I. Short stay-time (<36 hours) and restricted radius of operations (~1 km) are matched to a relatively simple terrain with only one prominent feature, in this case the crater Censorinus. (The landing point currently being considered for Apollo is further from the crater rim.)

A mission to the complex Marius Hills area, on the other hand, requires a longer stay-time and rover mobility just to visit all the types of structure within a 5 km radius (Figure 3.2). A mission of limited capability to the same site would restrict us to Level I activities. Thus among the sites which have been discussed for Apollo, some are Level I because of operational limitations, but warrant deeper study; e.g. Tycho, Copernicus, Marius Hills.

Table 3.3 categorizes sites by required capability.<sup>(5,8)</sup> The divisions between the Levels are clearly not firm.

### 3.3 Constraints and Accessibility

The principal constraints affecting accessibility are communications and propellant budgets.

For unmanned landers the communications problem is primarily one of data return from limb and far-side sites. One solution would be a relatively simple orbiting system of relay stations, which could serve a number of missions. Another possibility is the combined orbiter/lander mission (analogous to Viking), where the single orbiter is designed to serve only its own lander.

For manned missions, communications for data return are in principle not required. In practice, there are great advantages in real-time mission planning to be gained from ground support, and this function is likely to persist from Apollo through Level II manned systems. Communications relay is likely, then, if far-side sites are to be visited.

Additionally, for Apollo there is a requirement for ground tracking of LM descent and ascent, which presently restricts accessible sites to  $\pm 45$  degrees in longitude. This constraint can be lifted to some degree for Apollo, in particular enough to consider Marius Hills an acceptable site, and is surely not a constraint on more advanced systems, such as LM-B.

The propellant budget is severely affected by operational constraints. Drawing on Apollo experience these are typically:

<u>Mission Phase</u>	<u>Constraint</u>
Translunar	Free Return or DPS Abort
Lunar Surface	Abort Anytime

The Free Return constraint permitted only a certain class of trajectories close to the Moon's orbital plane and access at some time to sites within a band about  $\pm 20^\circ$  around the equator. This constraint has been relaxed to DPS Abort capability for Apollo.

The DPS abort capability restricts motion to translunar trajectories from which the descent engine alone can effect a return. This allows a region similar to the above, but greater in extent. The latitude range is greatest on the  $0^\circ$  meridian, and falls off towards the limb.

The Abort Anytime constraint requires that the ascent stage can effect a plane change to the plane of the orbiter at any time. The nominal mission mode has the landing site close to the orbital plane at landing and nominal lift-off, but possibly far removed during the stay on the surface. Low latitude sites and low inclination orbits easily satisfy this requirement, but propellant requirements become very great for high latitudes and long stay times.

All the Level I sites listed in Table 3.3 are within the capability of Apollo J hardware. Several sites, of which the most important is Tycho, require elimination of the DPS Abort constraint. To reach the entire near-side the Anytime Abort constraint must be relaxed. The accessible area on the far-side is exactly equivalent to that on the near-side, but raises the communications problem mentioned above.

The Apollo Dual and CSM-LM/B systems have greater payload capability, and can therefore gain access to larger areas. The long (14-day) stay will impose a heavy propellant requirement to satisfy Anytime Abort in higher latitudes. This problem can be at least partially overcome with an additional LM/B in orbit to effect rescue landings. For specific missions, payload is traded off against the fuel for abort requirements.

TABLE 3.1  
TYPICAL LUNAR LANDFORMS

A. MAJOR TERRAIN TYPES - LEVEL I		REPRESENTATIVE SITES
1. <u>MARIA</u>		
EASTERN (IMBRIAN) MARE		LANDING SITE 2*
WESTERN (ERATOSTHENIAN) MARE		LANDING SITE 4, 5, 6°, 7*
SULPICIOUS GALLUS FORMATION		RIMA BODE II, LITTROW†
2. <u>HIGHLANDS</u>		
RUGGED TERRA		CENSORINUS†, DESCARTES†,
EJECTA BLANKETS		ABULFEDA
OLD FILLED BASINS		FRA MAURO†
OLD PITTED PLAINS		HIPPARCHUS
		SOUTHERN HIGHLANDS, NORTH
		POLAR REGION
B. LOCAL STRUCTURES - LEVEL II		
SMALL MARE CRATERS		LANDING SITES 2*, 4, 5, 6, 7*
SMALL IMPACT CRATERS		CENSORINUS†
LARGE IMPACT CRATERS		COPERNICUS†, TYCHO°
OLD (REBOUND) CRATERS		POSIDONIUS, GASSENDI
COLLAPSE CRATERS		MARIUS HILLS†
MARE BASINS		MARE ORIENTALE, MARE CRISIUM
CRATER CHAINS		HYGINUS, DAVY†
VOLCANIC CALDERAS		CRATER Y IN ORIENTALE
DOMES AND CONES		MARIUS HILLS†, DESCARTES
FLOWS AND RIDGES		LITTROW†
FAULTS		ALPHONSUS, HYGINUS

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°SURVEYOR LANDING

\*VISITED BY APOLLO 11 AND 12

†TENTATIVE APOLLO SITES

TABLE 3-2  
LEVEL II SITES RELATED TO  
PROBLEMS OF LUNAR SCIENCE

GEOLOGY AND GEOCHEMISTRY										GEOPHYSICS																		
AGE DATING					COMPOSITION					MAJOR PROCESS INDICATORS					SEISMOLOGY					GEODESY					HEAT FLOW			
"ORIGINAL CRUST"	TIME OF GIANT IMPACTS	MARE FLOODING	POST-MARE TIME SCALE	PRIMITIVE ROCKS	DEEP-SEALED ROCKS	DIFFERENTIATED ROCKS	TRANSIENT EVENTS	ATMOSPHERE	CRATERING			TRANSPORT		VOLCANIC/TECTONIC			AZIMUTHAL DEPENDENCE			ACTIVE SEISMIC		GRAVITY			GEODESY		HEAT FLOW	
									IMPACT	VOLCANIC	CHAIN	RILLE	EJECTA	GRAVITY FLOW AND SLUMP	FAULT	DOME	FLOWS	RIDGES										
TSERNIUS	?		*	*	*	?	?		*				*						*				*					
FRA MAURO FORMATION	?		*	*	*				*				*						*				*					
MOSTING C		*	*						*				*						*				*					*
LITTELOW		*	*		*	?	?		*			*	*				*	*	*	*	*	*						
ABULEDA	?		*		*	?	?	?	*	*	*	*	*		?		*	*	*	*	*	*						
HYGINUS		*	*		*	?	?	?	*	*	*	*	*		*	*	*	*	*	*	*	*						
RIMA BOBE II		*	*		*	?	?	?	*	*	*	*	*		*	*	*	*	*	*	*	*						
TYCHO	?		*	*	*	?	?	*	*	?		*	*		*	*	*	*	*	*	*	*						*
SCHROTER'S VALLEY		*	*		*	?	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*						*
ARISTARCHUS PLATEAU		*	?		*	?	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*						*
GASSENDI		*	*		*	?	*	*	*	?		*	*		*	*	*	*	*	*	*	*						*
ARISTARCHUS			*		*	?	*	*	*	?		*	*		*	*	*	*	*	*	*	*						*
DIONYSIUS			*		*		?		*	?		*	*		*	*	*	*	*	*	*	*						*
S. ALEXANDER	?	*	*	?	?			?	*	?		*	?		*	*	*	*	*	*	*	*						*
TOBIAS MAYER DOME	?		*		*			?	*	?	*	*	*		*	*	*	*	*	*	*	*						*
COPERNICUS C D		*	*	*	?	?	?	*	*	*	?	*	*		*	*	*	*	*	*	*	*						*
MARIUS HILLS		?	*	*	*	*	?	*	*	*	*	*	*		*	*	*	*	*	*	*	*						*
HADLEY-APENNINES	?	*	*	*	*	?	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*						*
ALPHONSUS	?		*		?	?	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*						*
COPERNICUS PEAK	?		*	*	*	?	?		*	?		*	*		*	*	*	*	*	*	*	*						*
COPERNICUS WALL	?		*	*	*				*	?		*	*		*	*	*	*	*	*	*	*						*
RIMA PRINZ I	?	*	*	?	?			*	*			*	*		*	*	*	*	*	*	*	*						*
HIPPARCHUS									?	?					?	*	*	*	*	*	*	*						*
DESCARTES			?		?	*				*					?	*	*	*	*	*	*	*						*
TSIOL KOVSKY	?		*	?	?	?			*				*		*	*	*	*	*	*	*	*						*
CRATER 211	?				?	*			?				*		*	?	*	*	*	*	*	*						*

TABLE 3.3  
CANDIDATE SITES: (NEAR-SIDE)

EARLY MISSIONS:  $\leq 36$  HRS. (APOLLO H TYPE) LEVEL

EASTERN MARE (APOLLO 11)	24°W	1°N	
WESTERN MARE (APOLLO 12)	23°W	3°S	
FRA MAURO	16°W	7°S	
CENSORINUS	33°E	0°	
LITTROW	32°E	22°N	I
TYCHO (RIM)	12°W	43°S	
FLAMSTEED P	44°W	5°S	
HIPPARCHUS	5°E	5°S	
MOSTING C	9°W	4°S	
GAMBART	15°W	0°	
DAVY	8°W	12°S	

LATER MISSIONS:  $\leq 3$  DAYS [APOLLO J TYPE (ROVER)]

HYGINUS	6°E	2°S	
RIMA BODE	4°W	13°N	
ABULFEDA	14°E	14°S	I
SCHROETER'S VALLEY	52°W	25°N	AND
COPERNICUS CENTRAL PEAKS	20°W	10°N	
DIONYSIUS	19°E	4°N	II
TOBIAS MAYER	29°W	16°N	
ARISTARCHUS	47°W	23°N	
ALPHONSUS	3°W	13°S	
LINNE	12°E	27°N	

POST APOLLO:  $\leq 14$  DAYS (APOLLO DUAL; LM-B)

MARIUS HILLS	51°W	12°N	
JURA DOMES	35°W	45°N	
HANSTEEN	52°W	1°S	
APENNINES/HADLEY	5°E	27°N	II
DESCARTES	15°E	13°S	AND
ZUPUS	52°W	17°S	III
RIMA PRINZ	45°W	25°N	
MARE ORIENTALE	90°W	20°S	
DAMOISEAU	62°W	5°S	

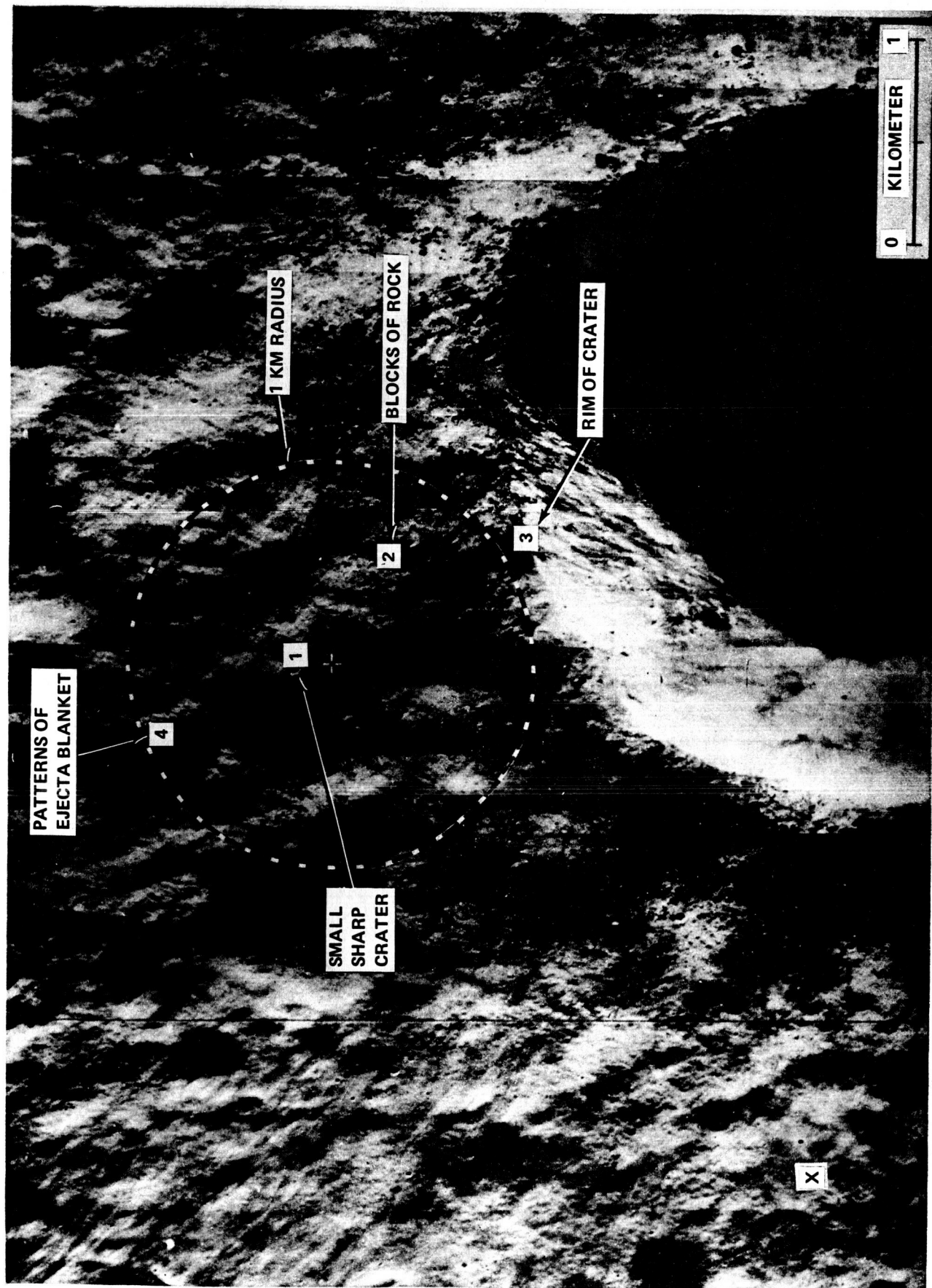


Figure 3.1 PROPOSED LANDING SITE FOR CRATER CENSORINUS  
SITE OF TYPICAL SHORT (~36 HRS.) MISSION

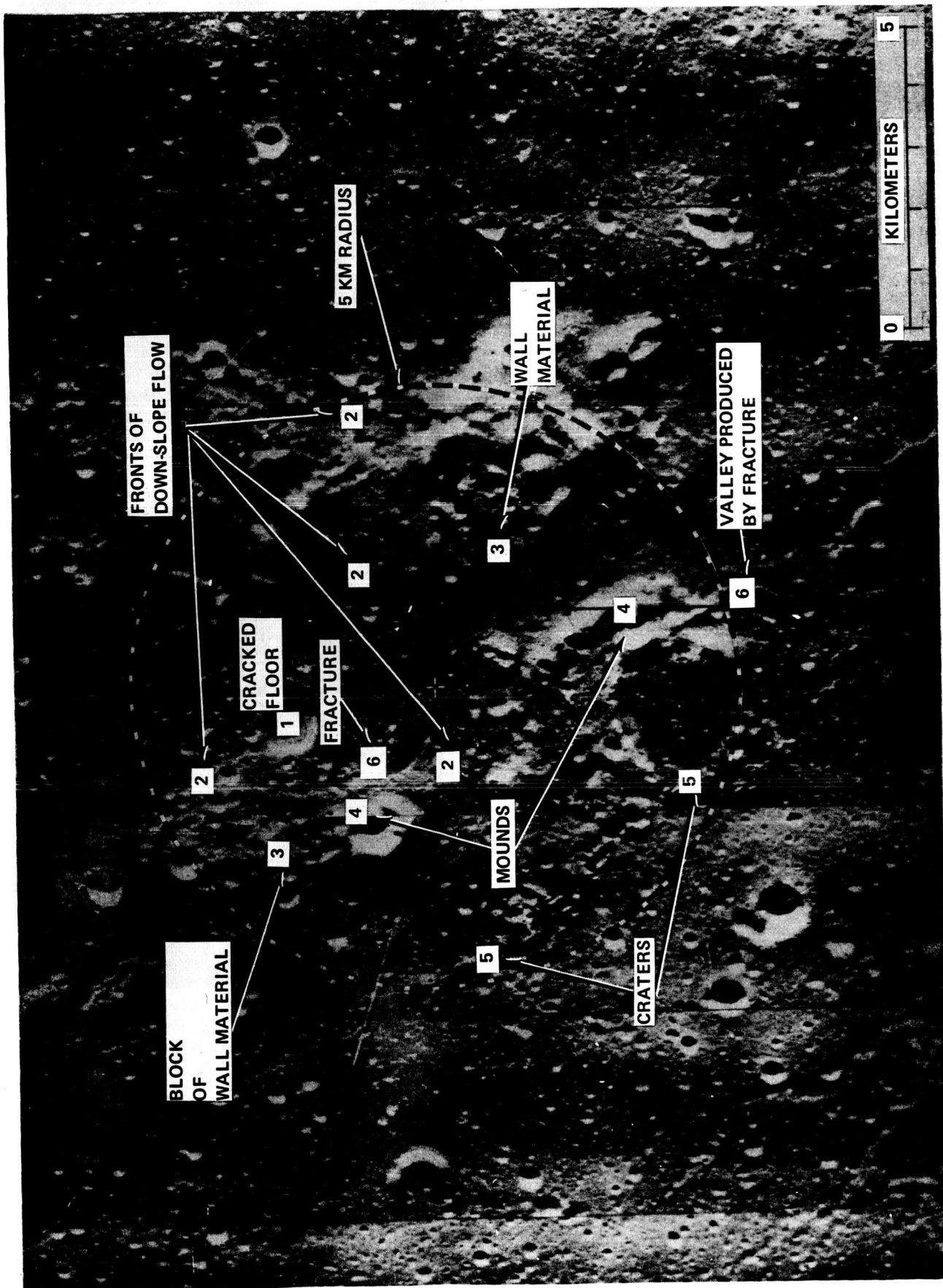


Figure 3.2 PROPOSED LANDING SITE IN THE MARIUS HILLS REGION  
SITE OF TYPICAL LONG (~3 DAYS) MISSION

#### 4.0 Systems

##### 4.1 Introduction

This section briefly describes the systems which potentially could support the objectives and missions of the above sections. The principal systems are shown in Table 4.1. They include Apollo J, "Lunar Viking", Apollo Dual Missions, and two CSM-LM/B Integrated Program Options, the Lunar Orbiting Base LM/B and Lunar Surface Base. Several additional historical program elements are described for completeness in Table 4.1 (Ranger, Surveyor, and Lunar Orbiter). Unmanned systems such as "Heavy Surveyor", which could be used alone in Level II, are not distinguished from Viking for purposes of this paper. Similarly, simple unmanned probes (ALSEP's, remote geophysical packages, hard landers), which would complement manned systems in Level II, are not described; this would require greater mission definition than we now have.

##### 4.2 Level I Systems

The unmanned system has been designated Lunar Viking, since the study has been based on the Mars Viking system.<sup>(12)</sup> The Viking spacecraft consists of a 2000 lb. orbiter and a 1000 lb. lander. It has an active life of more than 90 days. The launch vehicle for Viking is a Titan III-D Centaur, which can place approximately 12,500 lbs. in translunar injection.<sup>(9)</sup> This has considerable excess capacity compared with nominal Mars Viking size vehicles, and more than one spacecraft can be inserted with one launch. Possible combinations are:

- 1) One vehicle in high orbit and two vehicles on surface,
- 2) Four vehicles in low orbit
- 3) Three vehicles on surface

A Lunar Viking mission could be operated in conjunction with one of the manned missions, thus enhancing the return from both missions. For example, four high-altitude orbiters, involving one launch, could provide continuous communications for far-side and limb missions.

#### Apollo J

The next system is an Apollo follow-on.<sup>(10)</sup> This is similar to the latest Apollo J missions in that a standard Saturn V (106,000 lbs. in TLI) is used. The mission requires three men, and a 16-day CSM and 3-day LM. The CSM carries a subsatellite and/or science instruments for orbital sensing (~800 lbs. payload),

while the 2-man LM carries either a manned rover or a one-man flyer and advanced ALSEP for a total science payload of 1,000 lbs. The J mission rover weighs 450 lbs., and carries 2 astronauts as well as 170 lbs. discretionary payload over a range of about 90 km. A proposed one-man flyer carries an astronaut plus 370 lbs. of payload, and has a 12-mile range capability. This unit uses 300 lbs. of LM propellant. Larger flying units which have been considered can carry two men. Even if the Apollo system is virtually unmodified, a modest increase in capability should result from normal product improvements and operational experience.

#### 4.3 Level II Systems

##### Apollo Derivatives

Dual Launch Apollo<sup>(10)</sup> is selected as a typical Apollo derivative. This mode, which will place two men on the surface for 14 days, consists of two Saturn V (106,000 lbs. TLI for each vehicle) launches. The first launch carries a new system, the Lunar Payload Module, which emplaces 6,000 lbs. payload on the lunar surface. The propulsion system is a LM descent stage modified for automated landing. Once the unmanned launch has been successfully completed, the second launch delivers a 14-day CSM to lunar orbit and a 3-day LM taxi with 1,000 lb. science payload to the lunar surface. The astronauts then transfer to the Lunar Payload module, where they will live for 14 days. The LM taxi contains a one-man flyer (described above) and an advanced ALSEP package. Major components of the Lunar Payload Module are a dual-mode rover (manned or unmanned mode, 750 lbs. including 100 lb. payload, and 25-mile range in manned mode), and a science laboratory, in which in-situ analysis and selection of returned samples can be performed.

##### CSM-LM/B

The next mission class utilizes a single Saturn V-C launch to place a passive CSM in lunar orbit and a 14-day LM/B (8,000 lb. payload) on the lunar surface with three astronauts. The Saturn V-C is a four-stage vehicle, with the first three stages comprising an uprated Saturn V (120,000 lbs. TLI), and the fourth stage being a LM/B propulsion module (LM/B propulsion module has 50,000 lbs. gross weight). This launch vehicle can place 100,000 lbs. in lunar orbit, which in the present case will consist of CM, SM off-loaded by 28,000 lbs, two LM/B propulsion modules, one empty and one off-loaded by 12,000 lbs., crew compartment, and 8,000 lbs. payload. The SM propulsion system is used to return the CM and SM to Earth when the mission has terminated. The LM/B's are expended (or stored in Lunar Orbit).

### Lunar Orbiting Base - LM/B

The next mission mode is utilized by the integrated program. (11) It allows numerous 3-man, 28-day lunar surface missions. The LM-B can deliver a 20,000 lb. payload to the Moon, or carry a somewhat smaller, reusable payload. The Lunar Orbiting Base and LM/B's can be placed in lunar orbit either by the Saturn V-C or by the cislunar transportation system (Earth-to-orbit shuttle and nuclear stage). The Lunar Orbiting Base is a Space Station Module (50,000 lbs.) containing a considerable payload of remote sensing equipment. The LM/B shuttles between the base and surface sites, carrying three men for a 28-day stay-time with up to 20,000 lbs. of discretionary payload (Rovers, flyers, etc.). The LM/B's are reused. If the Saturn V-C is employed, a six man CSM is used for crew return to Earth. Otherwise, crew transfer is performed with LM/B crew capsules on the nuclear stage.

### 4.4 Level III Systems

The Lunar Orbiting Base - LM/B system, discussed above, is also appropriate to Level III.

### Lunar Surface Base

The final phase of the integrated program utilizes cislunar transportation to emplace and supply a long-term six-man Lunar Surface Base. Payloads between 50,000 lbs. and 280,000 lbs. are sent to Earth orbit by a Saturn V-A (the first two stages of the V-C), while those under 50,000 are boosted by the earth orbital space shuttle. The nuclear shuttle ferrying between Earth orbit and lunar orbit will insert about 100,000 lbs. into lunar orbit, and can return to Earth orbit with about 10,000 lbs. Operation from lunar orbit to lunar surface will be performed by the LM/B propulsion module. The first launch in the series will emplace a Space Station Module on the lunar surface to act as the Lunar Surface Base. Then six-man crews and LM/B propulsion modules will be transported to the base in future launches.

Essentially all the systems here are new developments. Similar capabilities have been studied in the past, employing systems more related to Apollo. These included Lunar Logistics Vehicles of 35,000 lbs. surface payload.

TABLE 4.1

LEVEL	TITLE	DESCRIPTION	ORBIT		PAYLOAD		SURFACE		COMMENTS
			TOTAL	SCIENCE	LANDED	SCIENCE			
	RANGER	DIRECT IMPACT	---	---	800 LBS	350 LBS	ATLAS-AGENA LAUNCH VEHICLE		
	LUNAR ORBITER	PHOTOGRAPHIC ORBITER	850 LBS	300 LBS	---	---	ATLAS-AGENA LAUNCH VEHICLE		
	SURVEYOR	SOFT LANDER	---	---	600 LBS	90 LBS	ATLAS-CENTAUR LAUNCH VEHICLE		
	LUNAR VIKING	UNMANNED ORBITER AND LANDER	2,000 LBS	125 LBS	1,000 LBS	70 LBS	TITAN III-D CENTAUR LV HAS 9200 LB. TOTAL ORBIT CAPABILITY OR 3300 LB. TOTAL SURFACE CAPABILITY		
I	APOLLO J	SIMILAR TO APOLLO 'J' WITH PRODUCT IMPROVEMENT	16-DAY CSM	800 LBS	16,600 LBS	1,000 LBS	OPTIONS INCLUDE ROVERS, FLYING UNITS		
	APOLLO DUAL	TWO SATURN V LAUNCHES FIRST UNMANNED LANDER SECOND MANNED LANDER	16-DAY CSM 16-DAY CSM	800 LBS 800 LBS	16,600 LBS 16,600 LBS	6,000 LBS 1,000 LBS	NEEDS MODIFIED LM DESCENT STAGE FOR AUTOMATED LANDING NEEDS DEVELOPMENT OF LUNAR PAYLOAD MODULE		
	CSM-LM/B	SINGLE SATURN V-C LAUNCH 14-DAY SURFACE OPERATIONS	16-DAY CSM	800 LBS	36,500 LBS (LM/B)	8,000 LBS (LM/B)	NEEDS UPDATED SATURN V NEEDS LM/B DEVELOPMENT		
II	LOB LM/B	MULTI-LAUNCH MISSION SSM IN LUNAR ORBIT 28-DAY SURFACE OPERATIONS	50,000 LBS (SSM)	3,700 LBS	50,000 LBS (LM/B)	20,000 LBS (LM/B)	NEEDS SHUTTLE TRANSPORTATION ALLOWS 3-MAN 28-DAY SURFACE MISSIONS OVER TOTAL SURFACE		
	LSB	MULTI-LAUNCH MISSION SSM ON LUNAR SURFACE	---	---	50,000 LBS (SSM)	20,000 LBS (LM/B)	NEEDS SHUTTLE TRANSPORTATION LM/B USED FOR LOGISTICS AND VISITS TO OTHER SITES		
III									

## 5.0 Sensitivities and Program Interfaces

### 5.1 National

Any discussion of this kind is sensitive to variables external and internal to the NASA program. External variables -- national priorities, the state of the economy, international affairs, need for national prestige -- affect the overall ambition of the NASA program, but not necessarily the relative priorities within the program. Overall guidance to NASA from the President and Congress, for instance, on the relative balance between unmanned and manned flight, may set the flavor of a proposed lunar program; but the principal effect of, for instance, the current budget climate, is to eliminate or delay the more costly options.

### 5.2 NASA Program Interfaces

Program Interfaces within NASA have strong effects on choice of system and cost, particularly where common systems are concerned.

In the Space Task Group Report of Summer, 1969, lunar exploration is resumed with systems common to Earth-orbital and manned planetary programs, in particular, the Lunar Orbiting Base (or Lunar Orbiting Space Station) and LM/B. In this context, these become highly favored systems, at a schedule set by the overall plan.

In the shorter-term context of an on-going Mars Viking program, lunar use of Viking deserves serious study, which will be pursued this year.

The Skylab program of course evolved from Saturn-Apollo and has much in common with it. The principal effect on the lunar program has been the transfer of the launch vehicle for Apollo 20 to Skylab, and the serious consideration of diverting the Apollo 18 and 19 vehicles.

The high cost of Saturn-Apollo systems has led to shutting down Saturn V production. It is not unlikely that the shutdown will persist and eliminate the otherwise strong options of Apollo J and Dual Apollo systems from consideration.

It should be noted that manned lunar missions require a large launch capacity. Flying any manned missions in the near future requires either restart of Saturn V production or the development of a replacement launch vehicle of lower cost, but relatively large payload (perhaps 150,000 lbs. in Earth orbit).

### 5.3 Manned Planetary Program

Since the Moon is sometimes proposed as a "test-bed" for planetary exploration, interfaces with such a program are potentially important. Reasonable "earliest dates" for commitment to a manned Mars landing fall in the 1975-85 period.

It is difficult to argue that there is a "requirement" for precursor lunar exploration, and it appears unwise to attempt to justify a lunar program on these grounds. The Martian environment (gravity and atmosphere in particular) is sufficiently different from the Moon and other planets that the Moon can hardly be a better systems test bed than, for instance, the Earth. The most important precursor test is the qualification of man for the flight. Prolonged lunar surface exposure could contribute here, but any "requirement" is probably for a long duration, orbital test.

The primary values of a Lunar Program to a Planetary Program would appear to be experience and confidence. The experience in designing Ranger, Surveyor, and Lunar Orbiter has been valuable to the Mariner and Viking programs. Perhaps more important is the operational experience in setting up mission control and data analysis.

Taking this point of view, one might describe a manned Mars mission as a long duration mission (2-3 years) with between a month and a year (opposition and conjunction class opportunities) at the planet, with communication time lags as great as 25 minutes round-trip. The system would surely involve an orbiter (mission module and return propulsion), some number of landers, and probably complementary unmanned probes.

Remembering that the planets are different, and that the "right" way to explore the Moon could very well be the wrong way to explore Mars, this would incline the choice of new systems to LOR systems with substantial remote sensing capability (C/SM-LM/B, Lunar Orbiting Base-LM/B). There is no question but that one would feel more secure about a Mars mission if lunar missions out of communications contact (e.g., with the one-hour occultation of a low orbit communications relay) were a familiar occurrence. Confidence would be further improved if, as in the Integrated Program, many of the systems and subsystems had had extensive use in cislunar space.

#### 5.4 Lunar Surface Base

The Space Task Group report and current NASA planning hypothesize a lunar surface base in the early or middle 80's. If such a base is a goal, it would influence planning for the previous years. The purely scientific rationale for such a base is not clear. Individual sites in Level III may warrant prolonged investigation (up to a year); the function of a permanent base must involve more than this.

Likely arguments arise from hypothetical engineering and logistics tradeoffs. Examples of such hypotheses are: reusable equipment is stored at the base between manned missions; it is advantageous to have a central base for propellants storage; indigenous resources are processed and prepared for use at the base. Similarly, facility functions argue for a base: support for Moon based telescopes; launch complex for planetary probes; 1/6 g biological laboratory; central geochemical analysis laboratory. It appears that, while the "gap" program might be strongly affected by an intent to emplace a permanent base, the kind of interim scientific operations discussed above will not by themselves lead to a requirement for one.

## 6.0 Summary and Conclusions

The present program, as amended by budget constraints, includes a gap in lunar activity of approximately ten years. This memorandum has considered a broad range of possible objectives and missions for this interval, and of flight systems to perform them. Loosely, the priorities are to complete the descriptive characterization of the Moon, then, to follow up on particular problems, and lastly, to study the Moon broadly and in considerable depth. A sequence of options in ascending order of ambition is presented. The first item represents a minimum program.

- 1) Adequate funding is required for the analysis of data obtained by the lunar program up to and including Apollo. This includes preparation of photo-geological charts of the lunar far-side to complete the characterization of the Moon. They may be used for future far-side investigations; and, if so, the scale of the charts should be in accord with this. ( $10^6:1$  scale is possible, but not necessary).
- 2) There is a strong role for orbital survey missions to obtain far-side global photographic coverage at intermediate resolution (comparable with Orbiter IV) and at both low and high sun angles. This could readily be done by an unmanned orbiter. Remote survey by the Apollo J missions is expected to identify additional survey instruments which might be of particular use on such an orbiter.
- 3) As surface missions are planned, there will be a requirement for high-resolution site-selection photography probably including stereographic data for good topographical descriptions.
- 4) There are a limited number of Level I (Characterization) surface missions, consistent with unmanned point landers (Surveyor - Viking) or 3-day Apollo. Completion of near-side characterization is not a large program. Some additional sites on the far-side, limbs, and poles, will be desirable.
- 5) While certain Level II activities match well with Apollo J missions and automated point landers, in general extended capability is required. In manned missions stay times of at least a lunar day are required. In unmanned missions, an automated roving vehicle or a substantial (many flight) sampling program is involved. For these programs, the tradeoff between in-situ analysis and automated sample return needs to be performed.

- 6) In Level II, particular studies at a variety of sites are involved. This favors a sequence of point landings (with local mobility) rather than a fixed base. CSM-LM/B and the Lunar Orbiting Base-LM/B system are consistent with this. The Lunar Orbiting Base-LM/B is analogous to our best impressions of a manned Mars mission.
- 7) Even in Level III, the scientific functions of semi-permanent bases in orbit or on the surface are not clear. It is believed that the "justification", if any, of such bases will derive from operational and engineering functions, such as refueling depots, storage for reusable equipment, emergency shelters, and elements contributing to safety in off-nominal missions.

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This work would have been impossible without the assistance and previous work of the Lunar Exploration Department at Bellcomm, particularly Noel W. Hinners and Farouk El-Baz.

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#### Attachments

Appendices A and B

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APPENDIX A

The fundamental goal of lunar exploration, as it is often stated, is the understanding of the origin and evolution of the Moon. To achieve this goal, the Space Science Board<sup>(2)</sup> has recommended that the following major investigations of global significance be undertaken.

Major Lunar Investigations

- 1) Age dating (crystallization, impacts and surface exposure).
- 2) Distribution of chemical composition, density, and elastic properties within the Moon.
- 3) Thermal state of the Moon.
- 4) Composition and processes of the major global units (i.e., Mare, Highlands, etc.)
- 5) Crustal tectonics (processes).
- 6) Abundance, composition and distribution of gases, sublimates and entrapped volatiles.
- 7) Organic materials.

Also important but of lower priority, are the studies of features and processes of less than global importance, such as small impact craters, wrinkle ridges, rilles, unconformities and the development of surface morphology.

APPENDIX BLunar Orbiter Photographic Coverage

Except for the polar areas, there is complete coverage of the near-side at a resolution of 60 to 90m. The high resolution (~1m) coverage of selected sites on the nearside comprises about 1% of the lunar surface.

Far-side coverage at a resolution of about 1 Km is essentially complete. About 1% of the far-side has been photographed at resolutions between 100m and 200m.

The Apollo CSM Orbital Photographic Experiment

## Panoramic Camera (Stereo)

- resolution ~2m from Apollo orbit
- field of view across track ~300 km
- coverage along ground track ~4% of lunar surface per mission
- planned for 3 missions (16-18)

## Metric Camera (mapping)

- resolution about 20m
- field of view ~120 km
- coverage along ground track ~2% of lunar surface
- planned for 4 missions (16-19)

Apollo CSM Orbital Science Experiments

Material Properties

- x-ray spectrometer
- $\gamma$ -ray spectrometer
- $\alpha$ -particle spectrometer
- EM sounder

Gravity

- S-band transponder

Atmosphere

- Mass spectrometer
- Far UV spectrometer

Thermal

- IR radiometer

Particles and Fields Environment

- Subsatellite (magnetometer, charged particles)

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